The Art and *Science* of Broaching

By Chris Van De Motter
To truly understand the benefits of broaching it’s important to take many things into consideration, including the various methods, materials, and machines involved.
Broaching is one of the most productive and precise metal-cutting operations performed today. It’s also one of the most misunderstood.

Broaching resembles planing or shaping, in that the broach tool presents a sharp cutting edge to the workpiece and moves across it, removing a predetermined amount of material. What primarily distinguishes broaching from other metal-cutting operations is the tooling used. A broach combines roughing, semi-finishing, and finishing teeth in a single line. Although many variations exist, the basic tool is an axial, multi-toothed rod, bar, or plate.

Broaching’s strengths are that it produces parts at a high rate, removes heavy amounts of stock, roughs and finishes in one pass, and permits the machining of complex contours and simple shapes alike.

Economical operation is another advantage of broaching. While initial tool costs generally are higher than for other metal-cutting operations, the cost per finished part is lower because of the high production rates broaching permits. Coupled with automatic or semiautomatic parts-handling equipment, unskilled or semiskilled operators can be employed, further reducing operating costs.

Broaches also make shallow cuts and perform finish operations, often yielding smoother surfaces than can be attained with other metal-removal processes. Some broaches have burnishing sections that impart almost any finish desired, thereby eliminating the need for grinding. In terms of productivity, repeatability, accuracy, and surface finish, broaching surpasses milling in any one plane of a workpiece.

There are two basic types of broaches: surface (external), and internal. Surface broaches cut on the outside of the workpiece, while internal broaches enlarge or change the shape of an existing hole.

**Surface Broaches**

The simplest surface broach is the slab broach, used for cutting flat surfaces. Considered a general-purpose tool, it squares the ends of parts or provides a reference surface for additional broaching or machining.

In applications involving hard surfaces or heavy stock removal, free egress (or “nibbling”) broaches are employed. They have sets of narrow roughing teeth positioned at a specific angle to the centerline and quickly remove material. Full-width teeth follow the roughing section and make semi-finishing and finishing cuts.

Slot broaches cut slots of various depths and widths. In operations requiring high production rates, slot broaching is faster and more economical than milling. Two or more slots can be cut simultaneously with the proper tooling and fixtures. It’s easy for standard slotting broaches to cut slots in the ends or sides of a workpiece. But that’s not the case when cutting a slot along the part’s length. Often, heavier stock removal rates are involved that demand application of a longer broach.

Contour broaches cut concave, convex, cam-shaped, contoured, and irregular surfaces to extremely close tolerances. Broaching these surfaces requires that they be parallel and not present obstructions in the broach’s path.

Manufacturers of turbine engines often use dovetail (or “pine tree”) broaches to create special forms in the compressor wheels that hold blades in turbine discs. This sort of broaching usually involves multiple passes, due to the heavy amount of stock
Pot broaches cut precision external forms such as involute spur gears, splines, slots, and special tooth forms. Pot broaching allows the task to be performed in a single pass, making it an economical, high-production process. It has replaced hobbing and shaping in the manufacture of many types of external gears. During pot broaching, parts are pushed or pulled through the bore of the pot-broach holder.

Straddle broaches incorporate two separate slab-broach inserts to cut similar (or identical) parallel surfaces on opposite sides of the workpiece in one pass. Straddle broaching’s advantage is that it maintains a more precise dimensional relationship between the two sides than would be possible with separate passes.

**Internal Broaches**

The round-hole broach is the simplest of the internal broaches. It produces close-tolerance parts and smooth surface finishes in high-production applications. The round-hole broach has a series of teeth that fully encircle the tool. Each tooth cuts on its entire outer edge. When broaching ductile materials, round-hole broaches that incorporate chipbreakers are required. They effectively break the stringy chips that form so they fall off the broach, itself.

A variety of hole shapes can be broached besides round ones. Internal broaches cut square, rectangular, octagonal, and hexagonal holes, as well as any other internal shape. All that’s required is the proper starting hole for inserting the tool.

One of the most common internal broaches is the keyway broach, which resembles a slot broach. A fixture called a “horn” usually supports the broach, locating the part in the hole where the keyway is to be cut.

To cut internal gear forms, an internal gear broach is used. Its tooth pattern gradually “nibbles” away at the workpiece’s internal surface, generating the desired gear profile. A full-form finishing broach may be needed to ensure accuracy and provide the optimum surface finish.

Broaching gun barrel bores necessitates a rifling broach. This special tool is very long so it can traverse the barrel’s full length. It has relatively few teeth, as barrel grooves are only a few thousandths of an inch deep. The broach machine pulls the broach through the bore while simultaneously rotating it to produce the spiral “rifling” pattern.

In some spline broaching applications, the pitch diameter must be precisely concentric with the part’s minor diameter. A concentricity broach ensures this because it has a full-form finishing section possessing alternating round and spline teeth that shave the minor diameter and spline form.

Cutting splines in thin-walled parts is always a problem. During the operation the walls expand with the broach’s passage but then “spring” back, leaving improperly cut splines. A cut-and-recut broach solves the problem. It has a “breathing area” behind the front cutting section that prevents part shrinkage. The front of the tool cuts the spline, than another cutting section at the broach’s end recuts it to precise tolerances.

**Horizontal vs. Vertical Machines**

The two most important factors to consider when selecting a broaching machine are the type of broach required for the application and the number of parts to be produced.
Machine size is determined by broach length, how much force will be exerted on the tool, whether it’s a push- or pull-broaching operation, and available floor space.

Horizontal machines are utilized primarily for pull-through applications. One-way (cutting in one direction) and two-way (cutting in both directions) models are available.

The automotive industry makes extensive use of large horizontal surface-broaching machines to remove heavy amounts of stock. These machines cut surfaces on large parts such as cast engine blocks, cylinder heads, manifolds, and bearing clusters. With carbide inserts, stock-removal rates of 1/4” or more are possible.

In the past most broaching was done on horizontal machines, but today they represent just 10 percent of all the broaching machines purchased. Vertical broaching machines have become more popular because they take up less space. This is an important consideration in plants where floor space is at a premium.

A drawback to vertical machines, though, is that they require a higher ceiling than horizontal models. In plants with low ceilings horizontal machines are still used, and they also find use as special, low-profile equipment for transfer lines and short-run applications.

Vertical machines typically are used for surface broaching. In operation either the broach tool passes over the workpiece, or it remains stationary while the part moves.

**Workpiece Materials**

Almost any metal alloy is broachable, including soft materials such as brass, bronze, and copper. Nonmetallic materials—graphite, hard rubber, wood, composites, and certain plastics—can also be successfully broached.

Free-machining materials are easier to broach than tough, hard ones. In steels, machinability is closely related to hardness. Steels with hardness of Rc 10 to 30 are excellent candidates for broaching, with those in the Rc 16 to 24 range having the “ideal” hardness. Usually, steels harder than Rc 35 dull broach teeth too quickly, forcing frequent tool changes and regrinds. Cast and malleable irons allow more stock to be removed per tooth than steels, as do brass and bronze. Caution should be exercised when determining stock removal rates. Too heavy a cut will cause the broach to overload.

Broach hook angles vary between 0-degrees and 20-degrees+, depending on workpiece ductility. Brittle materials such as cast iron require a smaller hook angle, usually five degrees to 10 degrees. The softer alloys of aluminum and rolled steel pose special problems because they may adhere to the broach teeth during cutting. This can be controlled with proper sharpening, the right cutting fluid, adjustment of the cutting speed, and altering the step per tooth and tool geometry.

**Applications**

Each broaching operation is different, but there are five areas in which broaching excels: on parallel, multiple surfaces; when fast cutting is needed; automated operations; large production runs; and tough materials. The examples of typical broaching applications that follow illustrate broaching’s versatility.

Figure 1 shows an outer gear form that was pot broached. There are 31 teeth on the
diameter and the depth of cut of .156". The part is used in a transmission for locating clutch plates.

Figure 2 shows another example of pot broaching on various transmission parts. Each part has been broached using a push-up type broaching machine that loads the part under the pot broach tools and pushes it up through the pot. All of the splines or gear teeth are cut at the same time around the periphery. The part is completed in one pass on the outside diameter form. Typically, this operation will produce from 120 to 240 parts per hour.

Figure 3 shows the cam form for a couple of outer race parts in the transmission or drive mechanisms for an automotive manufacturer. Again, these parts were pot broached so that all the cam forms are completed in one operation. The difficulty in broaching these types of forms is the inherent cutting force that tends to turn the part as it is being broached. With the proper design of the tools, this situation is controlled and the proper form is broached equally spaced around the part.

Figure 4 shows parts that have been inter-nally broached to various gear forms. Both are transmission parts used by the automotive

CONTINUED ON PG. 50>
industry. Various sizes of internal gear forms and involute splines are used extensively in the automotive industry.

FIGURE 4

Considerations

Broaching is not suitable for every situation. Like any machining operation, it has its limitations. Several of these must be taken into account before determining whether broaching is right for a certain application.

The first consideration is the workpiece surface. If the surface to be broached isn’t parallel to the direction the workpiece or tool travels, broaching may be inappropriate. Also, if the broach’s passage over or through the workpiece is obstructed, another method should be sought.

Secondly, complex, contoured surfaces having curves in two or more planes can’t be formed in a single broaching pass, except in the case of broaching helical gear teeth. In helical broaching, the broach and gear teeth are uniformly rotated in relationship to each other. The gear and broach must rotate at the desired helix angle as the broach is pulled through the piece to obtain the proper relationship.

Finally, the broached part must have sufficient strength to resist the forces exerted by the broach. Likewise, these forces also demand that machines and fixtures be rigid. Parts with thin walls or cross sections may prove too fragile for broaching. This is true for narrow slots as well, because the broach tools would have to have extremely thin cross sections.

Broaching won’t solve every metal-cutting problem. But if the workpiece design and production volume lend themselves to it, broaching could prove to be the most efficient, least costly way to manufacture top-quality parts.

ABOUT THE AUTHOR:

Chris Van De Motter is president of The Ohio Broach & Machine Company, which is located in Willoughby, Ohio. To learn more call (440) 946-1040, send e-mail to sales@ohiobroach.com, or go online to www.ohiobroach.com.